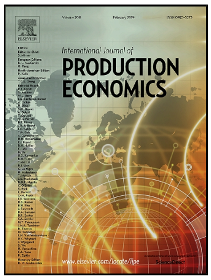

Making sense of blockchain technology: (How) will it transform supply chains?

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Title page

Making sense of blockchain technology: (How) will it transform supply chains?

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Making sense of blockchain technology: How will it transform supply chains?

Abstract

This research uses sensemaking theory to explore how emerging blockchain technology may transform supply chains. We investigate three research questions (RQs): What are blockchain technology's perceived benefits to supply chains, where are disruptions mostly likely to occur and what are the potential challenges to further blockchain diffusion? We conducted in-depth interviews with 14 supply chain experts. Cognitive mapping and narrative analysis were deployed as the two main data analysis techniques to aid our understanding and evaluation of people's cognitive complexity in making sense of blockchain technology. We found that individual experts developed different cognitive structures within their own sensemaking processes. After merging individual cognitive maps into a strategic map, we identified several themes and central concepts that then allowed us to explore potential answers to the three RQs. Our study is among the very few to date to explicitly explore how blockchains may transform supply chain practices. Using the sensemaking approach afforded a deeper understanding of how senior executives diagnose the symptoms evident from blockchains and develop assumptions, expectations and knowledge of the technology, which will then shape their future actions regarding its utilisation. We demonstrate the usefulness of sensemaking theory as an alternative lens in investigating contemporary supply chain phenomena such as blockchains. Bringing sensemaking theory to this discipline in particular enriches emerging behavioural operations research. Our contributions also lie in extending the theories of prospective sensemaking and adding further insights to the stream of technology adoption studies.

Keywords: blockchains; distributed ledger; sensemaking; cognitive mapping; supply chain; exploratory study; expert interview

Highlights

- We investigate how blockchains may transform supply chains.
- We adopt sensemaking theory to gauge foresights via expert interviews.
- We identify the perceived benefits of blockchains to supply chains.
- We establish potential areas where blockchains may penetrate supply chains.
- We elucidate the challenges of blockchain technology's further diffusion into supply chains.

1. Introduction

Blockchain technology (also known as distributed ledger technology) is essentially a peer-to-peer distributed asset database that can be shared across a network of multiple sites, geographies or institutions (Brown, 2016). The technology's core innovation lies in its ability to publicly validate, record and distribute transactions in immutable, encrypted ledgers (Swan, 2015). Many people believe that blockchain technology will have a profound effect on industries and societies once it creates a global network, allowing individuals, organisations and machines to transact with each other without having to trust each other or use third-party verification (Kinnaird and Geipel, 2017; Gaehtgens and Allan, 2017).

Blockchains have enabled the creation of decentralised currencies such as Bitcoin, self-executing digital contracts ('smart contracts') and intelligent assets that can be controlled over the internet, as in smart property (Wright and De Filippi, 2015; Kosba et al., 2016). Recent research on blockchains, which were first proposed by Nakamoto (2008), has largely focussed on financial transactions and distributed ledger systems (Pilkington, 2015). As a disruptive technology, however, the potential uses of blockchains could transcend the financial industry (Nofer et al., 2017). Because blockchains allow the secure exchange of data in a distributed manner, the technology could affect the structure and governance of supply chains as well as relationship configurations and information sharing between supply chain actors. If integrated with field-sensing technologies such as the Internet of Things (IoTs), blockchains could create permanent, shareable and actionable records of products' digital footprints throughout the entire supply chain. Such improved visibility would provide product traceability, authenticity and legitimacy – all of which are crucial to the food, pharmaceutical and luxury-item supply chains.

In practice, a number of piloting programmes across various sectors have tried to exploit the value of blockchains for supply chains. For example, in shipping, South Korea's Hyundai Merchant Marine (HMM) announced on 4 September 2017 that it had successfully completed its first pilot voyage using blockchain technology for shipment booking, cargo delivery and real-time container monitoring and managing (HMM, 2017). In the food sector, Walmart has stated that blockchain trials helped the company to reduce the time necessary to trace the movement of a shipment of mangoes from seven days to 2.2 seconds (McKenzie, 2018). In the energy sector, a consortium of companies, including BP and Royal Dutch Shell, plan to develop blockchain-based digital platforms for energy-commodity trading by the end of 2018 (Reuters.com, 2017). Blockchains have been deployed in the diamond sector to ensure diamond authenticity (Ambler, 2017) and in cross-border trade to ease the complexities of workflows (Barnard, 2017). These aforementioned initiatives are mostly permissioned blockchains where access is restricted to certain supply chain actors (We discuss this type of blockchain further in Section 2.1). Although blockchain technology's penetration level remains minimal, active sensemaking and exploration of the technology's potential value to supply chains are currently taking place.

Despite the aforementioned interest and efforts in practice, our understanding of blockchain technology's implications on supply chains remains limited. Our primary aim in this study is hence to discover how this disruptive technology will likely change the practice of supply chains. Consequently, our overarching research question is: 'How will blockchains transform supply chains?' Drawing on the theory of sensemaking, we try to understand how supply chain experts navigate the emerging technological landscape and interpret, contextualise and construct blockchain technology's potential business applications for supply chains. Through this enquiry, we expect to gain insights into the following sub-questions:

- RQ1: What are blockchains' perceived benefits to supply chains?
- RQ2: Where are disruptions mostly likely to occur?
- RQ3: What are the challenges to blockchains' further diffusion in supply chains?

The remainder of this paper is organised as follows. First, we define blockchains and their key attributes. We then review the related literature on the potential value of blockchains for supply chains. Following this review, we present our research methodology and discuss our research findings in depth. Finally, we describe implications for research and practice, as well as discussing limitations and opportunities for future research.

2. Background literature

2.1. Blockchain technology

In technical terms, blockchains are peer-to-peer distributed networks that are cryptographically secure, append-only, immutable (they are extremely hard to change) and updateable only through peer consensus (Bashir, 2017). Blockchains are another application layer that run on top of the internet protocols that enable economic transactions between relevant parties, without requiring a trusted third party (Tapscott and Tapscott, 2017). Blockchains can also be used as registry and inventory systems for the recording, tracing, monitoring and transacting of all assets, whether financial, legal, physical or electronic (Walport, 2015).

In a blockchain system, a list of transactions is recorded onto a ledger over a given period, creating a 'block'. As each transaction occurs, it is put into a block. Each block is connected to the blocks before and after it. These blocks are mathematically 'chained' together through a hashing function; – we could think of a hash as a digital fingerprint of data to lock it in place within the blockchain (Laurence, 2017). Once these blocks are connected within a chain, they become immutable: they cannot be changed or deleted by a single actor. Instead, they are verified and managed using automation and shared governance protocols (Swan, 2015). The verification is conducted by blockchain nodes (the computers/users participating in a blockchain network). Each node contains a complete record of all the transactions ever recorded in that blockchain. No single node controls the data.

When a new transaction or an edit to an existing transaction enters a blockchain, generally a majority of the nodes within the blockchain network must execute algorithms to evaluate and verify the history of the proposed individual block. If a majority of the nodes come to a consensus that the history and signature are valid, then the new block of transactions is accepted into the ledger, and a new block is added to the chain of transactions (Laurence, 2017). Therefore, the verification process, when used alongside modern encryption methods, can effectively secure the data in blockchain ledgers against unauthorised access or manipulation. This setup ensures that users always have access to a comprehensive audit trail of activities (Miles, 2017).

The unique nature of blockchains lies in their ability to create a self-correcting system without the need of third parties to enforce the rules. Instead, the enforcement is executed through a consensus algorithm. Some people claim that blockchains thus 'programme' the much-needed 'trust' in digital systems (Gaehtgens and Allan, 2017). There are two types of blockchain, based on the access control mechanism involved (i.e. who can read a blockchain, submit transactions to the blockchain and participate in the consensus process):

- *Public blockchains*. In this type, every transaction is public (and hence 'permissionless'), and users can remain anonymous; the network typically has an incentivising mechanism to encourage more participants to join the network. Bitcoin is a typical example.
- *Permissioned blockchains*. In this type, participants must obtain an invitation or otherwise have permission to join. Access tends to be controlled by a consortium of members (consortium blockchains) or by a single organisation (private blockchains).

The key attributes and claimed benefits of blockchains may be summarised as follows (Yli-Huumo et al., 2016; Gupta, 2017; Lansiti and Lakhani, 2017):

- *Disintermediation*. Because blockchains are peer-to-peer networks, they reduce reliance on third parties.
- *Transparency with pseudonymity*. The information within blockchains is viewable by all participants and cannot be altered by a single entity, thus creating trust and reducing fraud. Users can choose to remain anonymous or provide proof of their identity to others.
- *Security*. Various computational algorithms and approaches are deployed to ensure that the recording on the database is permanent, chronologically ordered and available to all

others on the network. Blockchains' distributed and encrypted nature makes them difficult to hack.

- *Automation*. Blockchains can be programmed to automatically trigger actions between nodes (such as payments or other events) once certain conditions are met. This quality enables the concept of smart contracts, which are computerised transaction protocols that execute contract terms.

2.2. Why blockchains are important for supply chains

Given the hype surrounding blockchain technology, it is important to understand how blockchains may add value to supply chains. Most of the academic literature on the link between blockchains and supply chains has been conducted from 2015 onwards. Because blockchain technology is still in the early stages of development, the academic literature on the subject is dominated by conference proceedings; only a handful of journal articles have been published to date. Hence we have drawn insights from literature from both academia and practice. The latter offers valuable details about piloting programmes and debates on a range of practical issues. We later used the insights gained from this literature review to guide the design and execution of our empirical research; these insights were also further corroborated by our research findings.

2.2.1. Transparency, authenticity, trust and security

Blockchain-enabled transactions (i.e. a series of transactions that are required to get a product from place to place) offer transparency to participating companies. For example, a block could be created for each transaction from the manufacture of a product to its distribution and sale. This level of transparency and visibility is essential for improving the traceability of the products and ensuring the products' authenticity and legitimacy. For real-time tracking, blockchains could be integrated with Global Positioning System (GPS) and radio frequency identification (RFID) tags (Abeyratne and Monfared, 2016). Because all data recorded within a blockchain is distributed among all network members, records of transactions and activities are open for every member to access, unlike in the traditional method of utilising a third party. Each participant can check the progress and location of the products and can share the same information within the system (Kim and Laskowski, 2016; MH&L, 2016).

This improved visibility provides an auditable trace of the footprint of a product, which is particularly attractive to industries where the provenance of a product is crucial. This aspect could boost consumers' confidence in vendors (Loop, 2017; Olavsrud, 2016). The transparency achieved in blockchains is also pivotal to building trust into the supply chain and may revolutionise how we understand and research trust in supply chains (Field, 2017). Previously, to build the necessary trust between supply chain actors (such as sellers and buyers), intermediaries and mechanisms such as banks and stamped documentation acted as a critical conduit of transactions between organisations. Trust among these supply chain actors tended to be low due to the lack of transparency and visibility, particularly within multi-tier supply chains (Kembro et al., 2017; Grimm et al., 2014). Long-term relational and financial commitments were often required to build trust within supply chains (Schoenherr et al., 2015). With blockchains, however, trust is embedded and programmed into the technological platform. Some claim that supply chain activities may be executed in this 'trustless' environment without the need for burdensome trust-building processes between organisations (Abeyratne and Monfared, 2016; Kharif, 2016).

Blockchains can also play an important role in stolen merchandise recovery and in avoiding fraudulent transactions (Loop, 2017; Apte and Petrovsky, 2016). Improved security is another motivational factor behind why blockchains may be adopted in supply chains, as they protect against tampering, fraud and cybercrime (Lohade, 2017; Burnson, 2017). To achieve security, both reliability and authenticity must be established. These qualities take the form of data integrity, one of the key attributes of blockchain-based ledgers (Yli-Huumo et al., 2016). The information stored within a blockchain is immutable once the information joins the linear chain. This immutability is due to the technology's distributed consensus characteristics, where only one true, verified version of the data is stored among all members of the network (Kim and Laskowski, 2016). Gupta (2017) pointed out that 'permissioned' blockchains are of particular value to businesses, as they offer enhanced privacy (because access to transactions can be determined by users' roles/responsibilities), auditability (since a shared ledger that serves as a single source of truth improves the ability to monitor and audit transactions) and increased operational efficiency (as transactions can be conducted at a speed more in line with the pace of business).

2.2.2. Efficiency and cost/waste reduction

Implementing blockchains could improve efficiency in logistics and supply chains, since the technology accelerates the transfer of data streams between parties (Bedell, 2016; MH&L, 2016). Hence, they could reduce the time products spend in the transit process, improve inventory management (Barnard, 2017; Loop, 2017) and ultimately reduce waste and cost (Kharif, 2016).

Smart contracts, mentioned earlier, are one of the key mechanisms to improving supply chain efficiency. Smart contracts are entirely digital and are written using programming code languages. The rules and consequences within a smart contract are defined in the same way that a traditional legal document would, stating the obligations, benefits and penalties (Gupta, 2017). The contracts can be automatically executed by a blockchain system, thus leading to high levels of automation and streamlined supply chain processes (Barnard, 2017). They are particularly useful for more complex multi-vendor outsourcing arrangements, in which several suppliers are jointly responsible for a particular outcome (Overby, 2016). Blockchain technology allows for the cascading of purchasing orders, invoices, change orders, receipts, ship notifications, other trade-related documents and inventory data across a supply chain, hence moving beyond basic matching to trigger threshold–based payments, replenishment, aggregation programmes and more. Improved data visibility further provides supply chain actors with an in-depth understanding of what consumers want as well as showing the demand for particular products. These abilities can help organisations plan more accurate demand forecasts and make better decisions (Loop, 2017).

Efficiency can be gained through the digitalisation of document transfers and the acceleration of the flow of data, particularly in the context of cross-border activities (Barnard, 2017). For example, in shipping, Maersk found in 2014 that a simple shipment of refrigerated goods travelling from East Africa to Europe might go through nearly 30 people and organisations, along with more than 200 different interactions and communications among them – a lengthy process that is vulnerable to errors, delays and the duplication of information submissions and records (IBM, 2017). In an attempt to address this problem, Maersk and IBM collaboratively developed a cross-border blockchain-based solution whose aim is to improve the workflow and real-time visibility of the status of each shipment; the system should facilitate highly secure information-sharing among trading partners (Barnard, 2017). For shippers, the planned solution could help reduce trade documentation and processing costs and help eliminate delays associated with errors in the physical movement of paperwork. The system will also provide visibility for shipping containers as they advance through the supply chain. For customs authorities, the solution is intended to provide real-time visibility, thus significantly improving the information available for risk analysis and targeting, which could eventually lead to increased safety and security as well as greater efficiency in border inspection clearance procedures. Another benefit is the accelerated tracking blockchains afford, which often reduces the tracking time from origin to completion from days to minutes (Bedell, 2016; Kharif, 2016).

Not only can efficiency be gained through removing wasteful activities from the supply chain; efficiency can also be achieved via preventive measures. For example, Kharif (2016) argues that blockchain initiatives could be used to monitor food safety and could help reduce spoilage and waste, and thus operational costs. Other benefits include better inventory management without the need for double verifications (Field, 2017) and positive environmental impacts via the use of paperless transactions (Field, 2017; Lohade, 2017).

Given the emerging nature of blockchains, most initiatives are currently (as of late 2018) in the piloting stage. While real-life, concrete and large-scale deployment is yet to emerge at the time of this writing, various sectors have a strong interest in actively exploring the potential uses of blockchain technology. For a list of piloting programmes and case studies as well as background information, the reader is referred to Wang et al. (in press, 2018), the UK Government Office for Science’s report on distributed ledger technology (Walport, 2015) and an EU report on blockchain technology for industrial transformations (Nascimento et al., 2018).

2.3. Sensemaking

Much of the previous literature on technology adoption and innovation diffusion has focussed on the implementation phase of the process, with less emphasis on the pre-adoption phase (Wisdom et al., 2014; Chong et al., 2015). Yet pre-adoption is an important process in which organisations become aware of a technological innovation, sense its potential disruptive effect, conduct an initial exploration and decide whether to embrace or ignore the innovation. Because technology adoption often involves substantial financial investment and a change in existing operations or even business models, having a robust sensemaking process in place during pre-adoption can play a critical role in aiding appropriate decision-making. Sensemaking is particularly important when organisational members face new and unexpected situations where the tangible benefits of an emerging technology are unclear, the disruptive effects are unpredictable and the technical advance paths are ambiguous (Weick et al., 2005).

While popular thinking such as institutional theory and the technology acceptance model can be used to explain why organisations adopt a given technology, such theories do not offer insights into how executives diagnose a new technology's symptoms and then develop assumptions, expectations and knowledge of the new technology, which then shape their actions. In our research, we use the theory of sensemaking to understand how supply chain experts perceive the potential impact of blockchains on their sectors. When radical innovations such as blockchain technology pose great challenges for managers and organisations, managerial sensemaking can serve as a vital cognitive process of reality framing, and it plays a fundamental role in influencing the strategic options actors use to form their future actions (Möller, 2010).

Originating from the enactment theory of organisations (Weick, 1977), sensemaking is often used in organisational and management studies to investigate the role of sensemaking processes in organising, decision-making and the use of strategic change initiatives (Gibia and Thomas, 1996; Weick et al., 2005; Sonenshein, 2010; Rouleau and Balogun, 2011), as well as innovative and entrepreneurial activities (Hill and Levenhagen, 1995). Marketing scholars have adopted sensemaking to explore the dynamic phenomena of business networks (Möller, 2010; Lundgren-Henriksson and Kock, 2016), while IT scholars have used sensemaking to examine the social aspects of IT adoption (Orlikowski and Gash, 1994; Lewis et al., 2011; Hsieh et al., 2011). Maitlis and Christianson (2014), in their review of the vast sensemaking literature, pointed out that while multiple streams of research have been conducted under the sensemaking umbrella, a single theory or definition of sensemaking is still lacking. In their attempt to integrate the common features they observed from the literature, they defined sensemaking as 'a process, prompted by violated expectations, that involves attending to and bracketing cues in the environment, creating intersubjective meaning through cycles of interpretation and action, and thereby enacting a more ordered environment from which further cues can be drawn (p. 67)'.

Sensemaking theory has its explanatory power at 'the organisational/group and individual/socio-cognitive levels, focusing on organisational actors' cognition and situated actions when introduced to a new technology' (Jensen et al., 2009, p.351). Sensemaking refers to the ongoing interplay of action and interpretation, where actors develop particular assumptions, expectations and knowledge of the technology, which then shape their actions towards it (Weick, 1990). Sensemaking process starts by bracketing where the technology is noticed, contextualised and adapted by individuals to the specific context of use (Weick et al., 2005). This step is then followed by the process of enactment, where meaning is created by connecting the cues (e.g. issues, events or crisis situations) to existing frames. Because sense is driven by plausibility rather than accuracy, sensemaking is based on plausible reasoning, and often on incomplete information (Weick et al., 2005). Therefore, sensemaking in our study is not a matter of truth but of one's understanding of what *may* be happening.

2.3.1. Prospective sensemaking

Sensemaking may be done either retrospectively or prospectively. Future-oriented sensemaking is critical when ambiguous situations require managers to develop novel understandings in order to structure the future by projecting some desirable (or undesirable) state (Gephart et al., 2010). Those who practise prospective sensemaking seek to use past and present temporal orientations to envision a desired or expected future event (Gioia et al., 1994; Kaplan and Orlikowski, 2013). In our research, we focus on managers' prospective sensemaking perspectives and extricate their conscious and intentional considerations of the probable future impact of blockchain technology. This forward-looking approach inevitably builds on people's views of the past and present. It is through the dynamic interplay among the interpretations of past, present and future that managers try to project how blockchains may become diffused within supply chains in the future. Classic work on sensemaking tends to frame it as a retrospective process (e.g. Weick, 1995); the process of prospective sensemaking is less understood and remains under-developed (Maitlis and Christianson, 2014). Through our empirical enquiry, we hope to create further insights in this area.

Sensemaking, particularly prospective sensemaking, overlaps somewhat with Endsley's (1995) concept of situational awareness, or SA – i.e. the perception of elements in the environment within a volume of time and space, the comprehension of their meaning, and the projecting of their status in the near future. SA is achieved via the process of situation assessment, which encapsulates three hierarchical phases: perception of the elements in the environment (level 1), comprehension of the current situation (level 2) and projection of future states (level 3). Both approaches are concerned with the generative mechanism of how people try to understand what is going on and what might take place in the future. Both claim that cues play a central role in triggering the process. The main difference between sensemaking and SA lies in the conceptual argument that SA takes data as a given, and that people notice and make inferences about data, while sensemaking asserts that people use their 'frames' (described below) to define what counts as data in the first place (Klein et al., 2007).

2.3.2. Framing

Our research focusses on individual sensemaking, which is typically grounded in the social cognition literature. This stream of research tends to examine various frameworks such as schema, schemata, interpretive schemes, mental maps or representations, on which individuals draw to make sense of a given situation (Maitlis and Christianson, 2014). These different forms of frameworks are known as frames: an explanatory structure that defines entities by describing their relationship to other entities (Klein et al., 2007). Sensemaking, in this sense, is the process of fitting data (e.g. particulars) into a frame (e.g. an explanation) and then fitting a frame around the data. Using an iterative process of framing and reframing, individuals filter and interpret the data, develop a coherent account of what is going on and create specific meanings in a given setting (Fiss and Hirsch, 2005).

Goffman's (1974) original conceptualisation of frames indicates that frames are schemata of interpretations that allow actors to make sense of ambiguous and varied signals; namely, frames shape how individual actors see the world and perceive their own interests. Goffman (1974) notes that people have multiple frames from which they can draw at any given moment, and that when we come upon a new experience, we tend to interpret it consciously or unconsciously in light of our existing frameworks. Research in managerial cognition has long established that cognitive frames direct managerial attention and thus influence firms' responses to changing circumstances, thus leading to cognitive re-orientation and strategic changes (Kaplan, 2008; Thomas et al., 1993; Balogun et al., 2015).

In the context of technological sensemaking, frames may be regarded as the understanding of a particular technological artefact that includes not only knowledge about the technology itself but also includes local understandings of specific uses in particular settings (Orlikowski and Gash, 1994; Mishra and Agarwal, 2010). This contextualisation is an important dimension in our treatment of blockchain sensemaking, as the meaning of blockchain technology can only be described (and its significance appreciated) in the context of the technology's use and its users – in our case, blockchains' potential value for supply chains.

3. Research methodology

We have adopted a qualitative, explorative approach in our research. We chose to engage with supply chain experts in order to gain in-depth insights into how supply chain practitioners navigate and make sense of the emerging landscape of blockchain technology. Eliciting experts' viewpoints is a popular method in the field of technology forecasting (Bokrantz et al., 2017; Melnyk et al., 2009; Iden et al., 2017). Experts in a particular problem area may possess knowledge of the causal structures of a particular system and are 'likely to have reasonably well-grounded appraisals of the state of affairs in the topics of concern' (Scapolo and Miles, 2006, p.682).

Research in sensemaking has found that experts and novices deploy the same types of reasoning strategies, but the experts have the advantage of a much stronger understanding of the situations under consideration; they also have more experience and knowledge about cause-and-effect relationships and thus generally produce more insightful comments (Klein et al., 2007; Dew et al., 2009). Because experts' mental models tend to be richer in terms of having greater variety, finer differentiation and more comprehensive coverage of phenomena, their comments tend to be deeper, more plausible and more sensible to context (Klein et al., 2007). Experts also tend to show much more anticipatory sensemaking and to identify actions that must be taken (Rudolph et al., 2009).

One popular method for engaging experts is known as the Delphi study approach (see Kembro et al., 2017; Bokrantz et al., 2017), which allows for anonymous interactions between dispersed panel experts in order to collect group judgements about the subject matter. Our approach is different. As discussed in Section 2.3.2, we are interested in examining individual sensemaking and how individuals develop their own interpretations of the emergence of blockchain technology. Our intention was to capture and preserve the diverse range of viewpoints and mental maps from individual experts first, and then to explore whether patterns or clusters might emerge if we later built a collective cognitive map (see Section 3.2). Therefore we adopted semi-structured interviews as our main data collection method. The use of expert interviews is an effective data collection technique, especially when researchers are exploring a new, emerging or under-investigated field (Bogner et al., 2009; Littig and Pochhacker, 2014; Yousuf, 2007). Individual expert interview can also mitigate the polarization effect in group judgement of a typical Delphi study (Winkler and Moser 2016).

3.1. Data collection

Our target interviewees were supply chain experts who have sufficient understanding of blockchain technology and can contextualise its use in supply chains. These are senior executives/managers who had in-depth domain knowledge in supply chain management with a sufficient understanding of IT, or they had expertise in IT management with a sufficient understanding of supply chain practices; some had expertise in both. We should note that they were not necessarily blockchain experts, given the emerging nature of the technology, but they did need to be able to understand its technological attributes and to contextualise its potential use in supply chains. We refer to them hereafter as supply chain experts.

To ensure the validity and reliability of the research results, we utilised the expert selection guiding principle from the Delphi methodology (Hasson and Keeney, 2011; Ecken et al., 2011; Bokrantz et al., 2017). We followed the three criteria proposed by Bokrantz et al. (2017) and Heiko and Darkow (2010) for the selection of industry experts: (1) position and responsibilities within the company, (2) knowledge and experience within the field and (3) willingness and time to participate. All our selected experts had at least 10 years of experience in the fields of IT and supply chain management. All held senior positions in the organisations they served. We also deliberately chose experts who held different responsibilities in their organisations so that they would represent a variety of viewpoints.

The potential candidates for interviewee were identified and selected from the research network the authors have built over the last decade. The long-term relationships between the practitioners and the academic researchers gave us confidence in the credibility of the experts' inputs. Following guidelines on purposive sampling and data saturation (Francis et al., 2010; Guest et al., 2006; Glaser and Strauss, 2017) and considering our resource and time constraints, we used an initial target number of interviews of between 10 and 20. Our sampling stopped when we sensed that we had reached data saturation, i.e. very few new insights were being gained from the process. In total, we conducted interviews with 14 supply chain experts (Table 1).

A semi-structured interview protocol (Appendix 1) was developed in which the questions focussed on how the interviewees had first noticed blockchain technology and how they had made sense of this emerging technology, what their perceptions were about the technology's potential impact (both negative and positive), and possible applications within supply chains. We started with general questions centring on how individuals started their sensemaking process about blockchain. We then design specific technical questions to establish a) whether our interviewees have sufficient understanding of the technology itself and b) of they do, the constructed meaning they have developed about blockchain and its disruptive impact. We then ask supply chain specific questions to allow our interviewees contextualise the blockchain use in supply chain, and to explore their cognitive framing on various issues emerged from this contextualisation.

Given the technical complexities and the embryotic state of blockchain technology, we developed a pre-interview information pack to acquaint the interviewees with essential background information. This priming technique proved effective and was welcomed by our informants, even those with IT specialties who sufficiently understood blockchains. The information pack contained a background introduction about the rationale of our research, a YouTube video link introducing what blockchains are and how they work, a list of piloting schemes observed in practice, and the list of interview questions. All interviews took place between June and August of 2017. Most interviews lasted between 90–120 minutes, with only one exception: one 45-minute interview was cut short by a disruption, but we compensated for the brevity by further elaborations and discussions via email and telephone conversations. All interviews were voice recorded and transcribed, although interviewees F and G stressed that they did not wish us to directly quote their comments in the paper due to information sensibility.

Table 1: Summary of interviewees

ID	Organisational role/responsibility	Location
A	Global head of logistics strategy and innovation	UK
B	Global logistics controller	Switzerland
C	Head of customer systems	Switzerland
D	Supply chain manager	UK
E	Process, innovation and technology improvement senior manager	Indonesia
F	Regional operational account manager	Germany
G	Logistics expert	UK
H	Global optimisation and analytics manager	Romania
I	Corporate IT customer systems manager	Switzerland
J	CEO: logistics service provider	Indonesia
K	Logistics consultant	Indonesia
L	IT consultant	UK
M	Productivity systems and solution manager	Portugal
N	CEO: IT service provider	UK

3.2. Data analysis

Our data analysis followed an iterative process of moving back and forth between the collected data, the blockchain technology literature and our emerging framework of sensemaking. We began by writing up a high-level summary of each participant's response in relation to our questions, which gave us a holistic sense of how individual informants perceived blockchain technology in the context of the supply chain environments where their organisations resided. We then performed a more detailed 'open coding' analysis of the transcriptions. The first few transcripts were independently coded by all authors. Codes were applied to substantive matters (e.g. exemplar examples discussed and events [cues] that triggered sensemaking), emotions/ways of thinking (e.g. beliefs that underpinned certain statements, or feelings about blockchain technology's disruptive impact), behaviours/actions (e.g. how individual experts interpreted and assessed the technology and predicted its future use) and other unexpected stances.

Our next stage of data analysis involved all researchers comparing and compiling all codes. A set of codes was agreed on and grouped together into categories based on the questions that guided our study; this step formed a working analytical framework that was then applied by indexing subsequent transcripts.

During the third stage, cognitive mapping was deployed as a data analysis technique to aid our understanding and evaluation of people's cognitive complexity in making sense of blockchain technology. This is a well-established modelling technique for issue structuring and for uncovering solution options (Montazemi and Conrath, 1986; Eden, 1988, 1992; Swan, 1997; Brun et al., 2014; Ferretti, 2016). Eden made a notable contribution by developing the cognitive mapping technique in the fields of operational research (OR) and operations management (OM); he proposed this technique as part of the strategic options development and analysis (SODA) methodological approach (Eden, 1989). SODA, soft systems methodology (SSM) and others all belong to the same suite of problem-structuring methods ('soft' OR), which are qualitative approaches for making progress with ill-structured problems. For further details about how cognitive maps might be analysed for the purpose of structuring issues or problems, the reader is referred to Eden (2004). For an application of this technique, refer to Eden and Ackermann (2004).

The aim of using cognitive maps, which are usually derived through interviews, is to represent the mental models through which people perceive and make sense of complex problems (Kolkman et al., 2005). A cognitive map consists of nodes (known as concepts), linked by arrows. The concepts include ideas and issues that have some meaning for the people involved and, as far as possible, are expressed in the words they use (Pidd, 2011). The arrows represent causal links between the concepts. The arrows may include a sign at the arrowhead, although the absence of a sign is usually taken to indicate a positive link, while a negative sign indicates a negative link. A cognitive map generally contains a hierarchical structure: goals statements on the top layer, strategic directions or important issues on the middle layer, and options and actions on the bottom layer (Eden, 2004). The more complex the map, the more complex the issue under investigation.

Figure 1 here

As depicted in Figure 1, we began by developing a cognitive map for each interviewee. The maps show how our interviewees expressed their thinking about various strategic issues related to blockchains. These individual maps were then merged into a single strategic map by examining the links, differences and similarities between individual maps. To merge individual maps, we followed the four processes suggested by Pidd (2011):

1) overlay similar concepts atop of one another in the strategic map;
2) add extra links between the concepts people use by identifying any synergies or causalities;
3) preserve any hierarchies of links present in the individual maps;
4) identify any loops, clusters and core concepts found in the strategic map.

Our strategic map revealed various emergent properties and then formed the basis of our discussion of the research findings. As Eden (2004) suggests, one important analysis type for cognitive maps is clustering analysis, where researchers seek tight interconnections between nodes. A cluster might form where the nodes in each cluster are tightly linked to one another and where the number of arrows with other clusters are minimal. We then categorised the clusters we had identified from the cognitive mapping into frames.

Scholars of managerial cognition tend to sort frames into diagnostic and prognostic categories (Gastano et al., 2017; Kaplan, 2008). In our case, the frame analysis involved understanding how actors deployed frames both to diagnose the emergence of blockchain technology and to forecast what future blockchain-enabled supply chains might look like. We categorised these factors into *benefits*, *applications* and *challenges* frames.

While the cognitive maps offered a structural view of the cognitive processes of the supply chain experts, we complemented this data analysis with rich narratives in order to provide further insights into the complexity of our interviewees' sensemaking. To demonstrate the level of consensus among the supply chain experts on certain concepts, we use tables (2–4) to summarise the key points derived from the interview data; the number of entries from the experts appear next to the key points. These tables should be interpreted with caution, however, as our study was explorative: we prioritised the inclusivity and relevance of the issues we discovered over the frequency with which interviewees mentioned issues. Some issues may not have been stated by most of the interviewees but could still be important factors to blockchain technology's further adoption within supply chains. Because blockchain technology is still in its infancy, as noted earlier, any early reduction of those indicators could come at the expense of meaningful conceptualisations during later stages.

4. Sensemaking: How supply chain experts frame emerging blockchain fields

Typically, our interviewees would start by describing how they had come to realise the disruptive effect of blockchains. Their noticing of blockchains was normally triggered by external stimuli (i.e. cues) such as competitors' activities, public media and blockchain advocates, and sometimes via the internal sensegiving process from their leaders or colleagues. They then would embark on a fact-finding process in an effort to understand what blockchains do in general. Some tapped into the research insights provided by consulting or IT companies, while others conducted their own market research. At this stage, they tended to ask whether the technology would really change everything, or if it was just hype.

Once they had obtained a general understanding, they started to contextualise what blockchains could enable their organisations to achieve in the particular environments where their businesses operated. They questioned whether certain benefits that had been observed or claimed elsewhere would be transferrable to their own industries. They would normally project a few sets of scenarios of how their organisations might respond to the emergence of blockchains and would consider several plausible alternative outcomes. Through analysing those outcomes, they would then tease out the potential benefits of blockchain use. They also tended to ponder the 'positive effect of benefits' frame versus the 'negative effect of challenges' frame and tried to achieve an integrative view of what blockchains would mean for themselves and for their businesses. A common theme among the supply chain experts was that although some applications would be beneficial, they tended to prefer small-scale applications that would deliver incremental gains rather than radical changes. They viewed this approach as a way to understand how to utilise the technology first before embarking on more ambitious adoptions.

4.1. Cognitive analysis

Due to space constraints, we cannot discuss the structural properties of each individual interviewee's cognitive map. Instead we use the cognitive maps of interviewees F (Figure 2a) and I (Figure 2b) as examples to capture the particular person's idiosyncratic ways of viewing the implications of blockchains within supply chains.

Figures 2a and 2b here

As shown in Figure 2, the goal-oriented statements are at the top of the cognitive maps. In our case, the common goal across all individual interviewees was blockchains' further diffusion within supply chains. At the bottom are detailed potential action points or options; these tend to be the issues and challenges that organisations must resolve if they wish to adopt blockchain initiatives. The middle layer typically contains potential blockchain application areas within supply chains, as perceived by our experts. Both interviewees F and I stressed that for any blockchain initiative, it must deliver value to customers (either existing or new). A blockchain-enabled supply chain should be thought of as a value platform within which supply chain actors should co-create value through a set of specific practices. Rather than developing a blockchain solution for the sake of it, organisations should instead identify areas with current problems in an existing supply chain that blockchain technology could then help to address, or new market opportunities afforded by blockchains that could lead to further market and revenue growth. Interviewee F, who was also more internally focussed, discussed the potential gains for his organisation in terms of time reduction and profit growth. Both interviewees shown in the figures believed that blockchains could eliminate some but not all intermediaries. They recognised that the built-in trust within blockchain-enabled supply chains would enable a number of blockchain applications. For instance, both highlighted the significant potential of smart contracts and product provenance. For interviewee F, process optimisation and cross-border import/export were also promising areas for future blockchain deployment.

Interviewees F and I both pointed out that the complex bilateral information linkages between organisations and the resistance from existing supply chain actors could pose a significant challenge/barrier to blockchains' further diffusion within supply chains. Interviewee I also indicated another major concern, which was that input data may be manipulated in blockchains – a serious problem that could threaten data integrity in supply chains. Interviewee I stressed that private blockchains would prevail in the future and suggested that the mandatory use of blockchains could help with further diffusion; interviewee F was more concerned about governance issues related to smart contracts.

Upon closer examination of our interviewees' cognitive structures, we found that the depth of detail and the multiplicity of aspects of the issues varied. In the case of interviewee I, the shape of his cognitive map is flatter, suggesting that he considered a wider range of choices and alternative views; with interviewee F, her cognitive map indicates a narrower focus on multiplicity but more in-depth thinking about blockchain technology's potential applications. According to Eden (2004), people can be considered cognitively complex if their cognitive maps have a relatively large number of nodes – indicating the recognition of and a concern for meeting multiple and possibly conflicting objectives. He further suggests that a simple ratio of arrows to concepts is a useful indicator of the degree of complexity of the map as a network. A higher ratio indicates a densely connected map, and supposedly a higher level of complexity. Interviewee F's and I's ratios were found to be 1.48 (37:25 arrows/nodes) and 1.32 (41:31 arrows/nodes), respectively, both of which are higher than Eden's suggested threshold of 1.15–1.20 arrows/nodes. This finding seems to suggest that both interviewees may be considered cognitively complex, thus validating their 'expert' status.

Having recognised the differences and similarities between individual maps, we then developed a strategic map to synthesise the collective sensemaking we found among all study participants. We followed the four steps discussed in Section 3.2 in merging the maps. Figure 3 is a strategic map that we produce with which the participants can all identify. In order to maintain the readability of the strategic map, we have not included all the hierarchical details. Our main concern is to identify all the central concepts and main linkages between those concepts evident in the map.

Figure 3 here

Eden (2004) suggests that clustering analysis can be conducted to reveal any 'chunks' among the issues that have surfaced via cognitive modelling. Note that we did not intend to conduct the clustering analysis at the individual level; we did this to avoid losing the richness of the data and potentially omitting elements that might have emerged as being important once we had built a collective strategic map. We were more interested in clustering analysis at the collective level, as this allowed us to identify any themes and patterns that might emerge among the experts. Each cluster that formed, and the interrelationships between the clusters, created summarising characteristics of the overall map. This strategy allowed us to explore the answers to the RQs raised in Section 1.

Consistent with the individual cognitive maps, the top layer of Figure 3 consists of goal-oriented statements and claimed/expected benefits (e.g. *value to customers* and *profit and market growth* as well as *operational improvement* and *time reduction*). Prognostic concepts are positioned at the top level as well. For instance, we noted a consensus among the experts that private and/or hybrid blockchain systems might be more suitable for supply chains, and in the future many blockchains will likely coexist. Others suggested mandatory use and integrative use with other technologies such as IoT, robotics, artificial intelligence (AI) and 3D printing. In the middle layer, we have highlighted four key concepts that the experts emphasised as being important application areas for blockchains in supply chains. They form four clusters (in **bold**). Each cluster includes further explicit ways of deploying blockchains. For example, the *extended traceability and supply chain visibility* cluster has four specific case scenarios (dispute management, product provenance, product monitoring and inventory management) as well as product recalls. The map clearly shows that three lower-level nodes, highlighted in ***italic bold*** – 1) the elimination of certain intermediaries, 2) the existence of visibility and transparency, and 3) having secure and distributed data records and transactions – are key enablers for achieving the four core blockchain applications. The bottom layer mostly contains a range of challenges or barriers that could prevent blockchains' further diffusion.

We now turn to a narrative analysis in the following sections to discuss the clusters and central concepts that emerged from the strategic cognitive map and how we organised these factors within three different framing processes.

4.2. The benefits frame

The *benefits* frame represents the degree to which supply chain experts perceived the potential of blockchain technology to add value to supply chains. Perceptions about the potential benefits of a technological innovation are a strong predicator for actual adoption (Davies, 1989; Venkatesh et al., 2003). Overall, the interviewees' perceived benefits of implementing blockchains in supply chains largely resonated with the literature findings.

Table 2 summarises the key insights; we have highlighted a few major insights to showcase the resemblance. The insights we obtained from the supply chain experts suggested that achieving supply chain visibility was where blockchains would likely begin to penetrate supply chains. This would then have a ripple effect, bringing other benefits such as process optimisation and automation. Visibility enables transparency, which is critical for orchestrating the whole supply chain. One interviewee said:

> The data quality normally is very, very good. That would as well lead to optimisation, so you can do a lot of things with the right data, and you can spot issues where exactly you have [*sic*]. For customers especially, the entire supply chain would be done faster. You should be able to cut points that do not add value to the business. So, the entire supply chain should normally get faster and less costly. (Interviewee B.)

Interviewee B believed that the enhanced security blockchains offered would protect products, trade and logistics information in the flow of data transfers and would offer strategic benefits to supply chains. Interviewees E and H also argued that integrating blockchains and the IoT would push the boundary of real-time supply chain (distributed) integration. For example, interviewee E noted that his organisation had built sufficient capability in using the IoT to track energy use and goods movement in warehouses. He envisioned the potential of blockchains as acting as a data reservoir for the IoT for improved and shared visibility among supply chain stakeholders.

The experts perceived blockchains as affording secure information exchanges by providing high-quality, consistent and tamper-resistant data records, thus streamlining data flows across organisations. Blockchain-enabled data security could also protect supply chains from the increasing cybercrimes and attacks of recent years. Supply chain systems' vulnerability was illustrated by the recent case of the 'NotPetya' cyberattack against the world's largest container shipping line, Möller-Maersk. The attack took place on 27 June 2017 and affected all of its business units' operations and resulted in US$300 million in lost revenue (Milne, 2017). As interviewee M said, 'Blockchain, by its nature, has no single point of failure and thus is more resilient'. Increased data security would also lead to increased confidence and trust in transactions between supply chain partners and end-consumers, 'particularly in those scenarios where supply chain partners are not very well known to each other or there are multiple tiers involved' (interviewee N).

Table 2: Perceived benefits of blockchains to supply chains

Benefits of blockchains to supply chains	**Explanation**	**Number of entries by experts**
Improves supply chain visibility	• Reduces the need for double-checking and guesswork • Allows the automation of data analysis activities (e.g. demand forecasting, asset monitoring, optimisation and lean improvements) • Allows the development of services such as track-and-trace • Crucial for implementation in cold chains and luxury-item supply chains to provide provenance and proof-checking • Information visibility improves internal business processes while adding value to the service/product for customers	A, B, C, E, F, G, I, J, K, L, M, N (12)
Ensures secure information sharing and builds trust	• One single data pool and system available to all stakeholders • Highly secure system behind blockchains, as demonstrated in Bitcoin • Standards can be set, thus increasing the overall quality of data in the entire chain • Built-in trust helps brands gain customer confidence	B, C, D, I, J, L, M (7)
Allows for operational improvements	• Increased volume/accuracy of data helps organisations better monitor and evaluate their performance • Opportunities to spot issues before they occur • Speeds end-to-end supply chain execution	B, C, D, F, I, K, L, M, N (11)

Note that the process of benefits framing is iterative and is closely connected with the interviewees' framing of blockchain applications. Our participants derived their perspectives of the potential benefits from the general use cases they had observed in various sectors as well as their projected use scenarios in the particular context of their businesses. They phased out observed benefits that did not seem to fit into their cognitive understanding of the supply chains. For example, when they were probed about their perceptions of the use of cryptocurrency in supply chains, the general reaction from the experts was that cryptocurrency would not become a reality for a long time; we thus saw little interest among the experts in further discussion of the matter (only two experts expressed interest). Rather, the participants tended to envisage areas where they saw that both feasible and tangible changes could be made for blockchain adoption in the short and medium terms. This outlook then led them to paint possible future states. They compared their current mental models with the future models and further articulated what the potential hurdles would be to reaching these future states. This contextualised understanding of blockchains helped them to substantiate and construct what blockchains meant to them.

The following sections discuss how the experts framed blockchain applications and challenges, respectively.

4.3. The applications frame

The *applications* frame captures the supply chain experts' subjective assessments about the areas where blockchains might penetrate supply chains. The potential blockchain applications were generally the 'ideas that are bouncing around' (interviewee K). These ideas represent the outputs of the supply chain experts' contextualisation of blockchains to specific supply chain settings. During the application framing process, we identified a variety of possible future scenarios the participants prescribed. We also found that their perceptions of the status quo were not static (i.e. not treated as a given). When we probed our experts about future possibilities, they also rethought and reconstructed past trajectories and present concerns. This behaviour was in line with the concept of 'temporal work' proposed by Kaplan and Orlikowski (2013), where the views of past, present and future are entangled in the sensemaking process. As a result, each individual's mental model about the future is different, contingent on his or her personal background, organisational position and experience, as well as firm and industry contexts and the prevailing technological paradigm (Kaplan, 2008). But after examining these mental models collectively via the strategic cognitive map discussed earlier in Section 4.1, we did observe the emergence of several common themes (summarised in Table 4), which we will discuss as follows.

Our interviewees acknowledged that while the technology is currently being implemented within supply chains, progress may be slow due to generally low levels of confidence and a lack of demonstrable financial benefits. Widespread, industrial-scale deployment will be necessary to achieve substantial impacts on supply chains, although this wider diffusion could take time to operationalise. One expert noted:

> Will blockchains have the same impact on logistics providers? My answer would be, not yet and probably not for a very long time, because if blockchains do become popular with logistics providers, their own propriety systems will simply feed the blockchain systems with data. Blockchains will not replace a logistics provider's own systems in the way they can replace a financial company's system. There is just too much going on in a logistics provider's internal system for them to be replaced by a blockchain. (Interviewee N.)

The experts viewed the value of blockchain technology to supply chain management in its extended visibility and traceability, its ability to create smart contracts, and the simplification, digitalisation and optimisation of supply chain operations.

Most interviewees (12 of 14) believed that blockchains would start to penetrate supply chains via product/shipment tracing and tracking, which would then lead to the benefits of product provenance and legitimacy.

> In terms of shipment tracking, the problem you have here traditionally is that you have to go through a lot of steps. There are a lot of partners, their own IT systems, their own databases and so on , and it is very difficult to have to integrate all these together. I can assure you, this is a mess. If you want to track a shipment, and it has to go from one continent to another, it is very, very hard to track. With blockchain solution, each partner becomes nodes of the network and they can see the data, with permissions of course. This will be very useful as it will improve the speed of shipments and delivery. (Interviewee M.)

Interviewees B, C, D, F, I and K pointed out that consumer markets have shown strong demand in knowing the origins of products and how they have travelled throughout the supply chain. This is where a viable business case could be established:

> I think there are more and more people who want to know where their food is coming from, especially for these kinds of fair-trade products. The application (of blockchain) could be extremely powerful I think. For supermarkets like XX I think, the people can scan the barcode of the product with an app, and they can see where the shipment of meat comes from, what the cows have been eating and whether they have been fed with pure grass or otherwise. You link customers with the products directly, plus you have this circle of trust that doesn't have any bias. (Interviewee B.)

The interviewees perceived that blockchain-enabled product provenance was of critical value and would likely have serious safety consequences for sectors such as aircraft manufacturing. Interviewee I pointed out:

> Taking the example of aircraft spare parts, it is very important to prove that this spare is accurate with this serial number. Made here, transported there and these are the people who owned it or anything else. So that when you build it into EasyJet's 737, they can be confident that it is the genuine piece and not counterfeit.

Similarly, interviewee C provided an example of a second-hand market he believed would be a viable deployment case for blockchain technology:

> Blockchain can be used to make sure that goods have not been tampered with, for example, when they are looking to resell a car, in order to ensure its true value. It may not change industries, but it's a very concrete deployment of blockchain technology, which actually creates value for consumers because you are sure of the information provided.

Three interviewees (G, J and D) also saw great potential in humanitarian supply chains, especially in finance and payments in cases where funds go missing due to corruption. Enhanced traceability would add value by mitigating the high costs and risks of quality problems, such as recalls, reputational damage and the loss of revenue from black- or grey-market products; in the most severe cases, such traceability could even prevent the loss of lives.

The interviewees perceived the simplifying, digitalising and streamlining of slow manual processes to be another potential deployment area for blockchains. Although supply chains can currently handle large, complex datasets, the general consensus among the interviewees (10 of 14) was that many of the existing supply chain processes, especially those in the lower supply tiers, are slow, and many still rely on paper:

> Basically, replacing the paper exchange through data and Hyperledger. That is cool stuff, and a good use of the technology. Not only it speeds up the flow of information, it helps tremendously the physical movement of goods as paper-based practices often cause delays. (Interviewee C.)

This problem is prevalent in sectors such as shipping. A few interviewees (A, B, G, J and K) felt that this was why Maersk and IBM had started their cross-border blockchain initiative: to address the complexities inherent in document exchange and verification in global trade. In this sense, blockchains are ideally suited to large networks of disparate parties and are a viable solution to reducing the complexity of global supply chains.

Smart contracts received more attention from our interviewees than from the literature:

> We have a lot of very big segregated customers. Basically, the contracts are all sorts of KPIs and all that which we have to fulfil and they define when we get paid based on that sort of stuff. So, I can imagine that linking that up would be having a system where we can commit to this and we both press the agree button, then it would execute automatically … So, if you ship 3,000 boxes of trainers for whoever, then you get paid for it immediately rather than having to go around the loops of 'is that done?' I think smart contract is a big area. (Interviewee I.)

The majority of our interviewees (12 of 14) concurred that smart contracts could be the most transformative blockchain application for supply chains. Smart contracts are becoming a desired functionality due to their flexibility and power to include business logic under certain conditions, thus removing costs and time from the supply chain via automation and self-execution. Smart contracts have become a highly targeted area for further exploration:

> Yes, absolutely, this is where our current (piloting) priority is – providing the smart contracts and providing the visibility for the customers, giving the supply chain transparency and orchestration of the entire supply chain. Obviously, there is a case scenario for using payment for the blockchain and, basically, making the payment reconciliation, however, it's a bit further away from what we're looking at. (Interviewee G.)

Although the added value that smart contracts offer may be significant, such contracts may also be where disruptions could be the most severe, as they have significant technological, legal and societal implications. Smart contracts could change the fundamental structure of existing supply chains and governance practices. Almost every interviewee agreed that smart contracts could take decades to become a supply chain norm.

In line with the literature, the interviewees considered permissioned blockchains to be a more viable option for centrally governed supply chains; restricted to known parties, who would have limited access to certain data segments only. Current supply chain actors are unlikely to accept open access, because revealing proprietary details such as demand, capacities, orders, prices and margins at all points of the value chain to unknown participants would be unwise. One interviewee mentioned:

> We don't want anyone else at random plugging in into the blockchain. We don't want anyone to be a node just because they feel like it. Someone was telling me just a few minutes ago that if you have a situation where anyone can just jump into your blockchain, they can easily overpower the network, use a Raspberry Pi and overpower the nodes. That's the whole network down. That's the last thing we want. Enterprises great, but individuals, maybe not. (Interviewee A.)

The transparency, visibility and security attributes of blockchains build trust in supply chains and can eliminate or at least expose any hidden unethical behaviours by certain supply chain actors. This embedded trust mechanism is particularly useful in supply chains such as humanitarian aid and pharmaceutical products. It is in these areas where corruption in the misuse of funds and the manipulation of product prices often occurs.

> We often find [corruption], for example, in the distribution chain of pharmaceuticals in our country. There are intermediating distributors that dominate the entire country's distribution channels. This gives them too much power and money, often resulting in unethical behaviours. Because they have such qualities, they are capable of manipulating distribution volumes and

> essentially prices in different areas. If blockchain is established within the entirety of such an industry's supply chain, producers will have clear visibility of where their medicines end up, and pricing and quality information would be crystal clear to the general public. (Interviewee J.)

Through their distributed consensual nature, blockchains also threaten the role of intermediaries in supply chains, which means that some traditional intermediaries could be phased out from the market, making room for other new intermediaries that provide blockchain-related services such as data analytics or integration. One interviewee touched on this point:

> I can really see that blockchain can remove customs clearance agents, because their operations are exactly like the blockchain. That would lead to a better-off system. Customs clearance is highly bureaucratic and labour intensive, and it could be easily automated through the technology. (Interviewee B.)

Others (B, H and L) thought disintermediation was possible but could take time to implement:

> I think that blockchain can replace freight forwarding [in the long-term]. There are companies out there working on freight forwarding automation. I am convinced these activities will be automated in the next 10 years, let's say. And the whole freight forwarding industry will change from its traditional forms. (Interviewee B.)

Not everyone agreed with this idea, though. Some claimed that as long as intermediaries add value to existing supply chains, they will not be phased out:

> Even if our customers choose to go away and engage with an asset-based company, direct to the trucking or direct warehouse, there will be so many parties. They would prefer to have one global contact rather than a decentralised 90 contracts with local providers. So, I don't see any issues in that. (Interviewee E.)

Some also believed that the expertise and knowledge of local intermediaries such as third-party logistics companies would still be required when managing localised operations (interviewees K, G and J). Nonetheless, disintermediation could take place in certain areas, resulting in job losses in the short term, though new intermediaries that offer blockchain-related digital services could emerge in the longer term, thus creating new employment opportunities. This situation would mean that job reskilling would be critical for supply chains to assure a smooth transition to a more digitalised supply chain ecosystem, as commented by Interviewee N.

Finally, some interviewees proposed the management of supply chain finance as a potential area of application. Two experts (interviewees L and I) asserted that cryptocurrency and a cashless society may be inevitable in the future, despite the current volatility of cryptocurrency trading in the stock market. This change would challenge governments' current supremacy in managing the national and international economic system and would also radically reshape the current structure of inter-organisational trade terms and cash flows. Interviewees D, E, L and M also suggested integrative use with other technologies such as robotics, AI and IoT as a potential way forward in blockchain deployment. One interviewee (A) also believed that linking blockchains with 3D printing could help to protect product design intellectual property. This stream of findings is summarised in Table 3.

Table 3: Supply chain areas where blockchains might penetrate

Supply chain areas where blockchains might penetrate	**Explanation**	**Number of entries by experts**
Providing extended visibility and traceability to stakeholders	• The improvement of visibility for end customers will raise service-level standards and value • This is an added feature achieved from implementing blockchains within a community of stakeholders and therefore will be achievable as the scale of implementation gradually increases	A, B, C, E, F, G, I, J, K, L, M, N (12)
Simplification, digitalisation and optimisation of supply chain operations (especially in a global context)	• Blockchains help to ease the current heavy workload on information transfer and processing • Blockchains help to manage transactions among multiple organisations, in particular for cross-border activities • Implementation should be specific to core supply chain operations such as information transfers between processes • This area will take the shortest time to develop and is potentially the most controllable area to pilot-test	B, C, D, F, I, K, M, N (8)
Smart contracts	• Potential applications: automatic validation of shipments, automated track-and-trace and multi-agent validation for information checking • These are more of a medium- to long-term application, as contracts may involve wider sets of stakeholders and greater scales; organisations should develop them once they are comfortable with blockchain technology's applications at smaller scales	A, D, F, H, I, K, N (7)
Trust building	• Ensure that humanitarian funds are distributed fairly and transparently and eliminate corruption. • Ensure that intermediaries such as distributors in certain industries do not manipulate the market and use their power to increase product prices	B, C, I, J, L, M (6)
Disintermediation	• Blockchains could potentially remove certain tiers of actors from supply chains that have the power to manipulate product prices and supplies • Will allow new intermediaries to emerge • Job losses could occur from the removal of intermediaries, hence the need to reskill the workforce • Will result in profound structural changes among supply chains	B, C, E, F, G, H, J, K, M (9)
Crucial supply chains/industries	• Initial implementation should be prioritised in crucial supply chains such as luxury items (e.g. diamonds) and key commodities (e.g. oil), or fast-moving supply chains (e.g. perishable items requiring a cold chain) • These supply chains have greater purpose and a sense of urgency for reliable, automatable networks of information transfer • If successful, implementation in these supply chains would create	B, C, G H (4)

	positive examples of how blockchains can benefit the supply chain industry	

4.4. The challenge frame

In our research, the *challenge* frame includes the issues that supply chain experts believe may negatively affect the further diffusion of blockchain technology. These frames formed the nodes (i.e. concepts) that emerged from our cognitive analysis, and they tended to have a negative sign associated with the arrowhead in the strategic map (Figure 3).

Due to the current infancy of blockchain technology, we noted a high degree of scepticism among our interviewees regarding the adoption of blockchains within supply chains (Table 4). A lack of understanding of the technicalities involved contributed to this scepticism and the low levels of confidence we noted: 'In our organisation there are very few people who understand it. I don't, I have heard about its application… The fact that I don't understand it entirely, of course means that I don't really trust it' (interviewee B). Because how exactly blockchains bring value to supply chains remains unclear, some interviewees questioned how necessary the technology was to the industry: 'Sometimes, people spend huge amounts of money, time, thinking [to deploy the technology], and when it gets down to it, we realise we don't really need it' (interviewee A).

Supply chains in general tend to involve multiple stakeholders, and convincing them to share data and participate in blockchains can be challenging – which further compounds the complexities of blockchain technology's adoption, as interviewee I noted:

> Data entry will be a huge hurdle… It is hard enough to get data anyway. The challenge of interface with anybody is already big enough. Sometimes, we have to develop software that reads the stakeholders' website to find out whether our product has arrived or not… And the customers are the worst. These are the people who we have just managed to train them not to send us faxes anymore.

Some of the supply chain experts we interviewed claimed that the transparency of publicly distributed ledgers would clash with the supply chain objective of a competitive edge based on information privacy; hence they viewed information sharing as a major hurdle:

> Transparency can create so many complexities. Having blockchain, we have not only the origin, identity of the product or activity, but we also have the value, the amount, and the

> decision-making process, so people will know what is happening behind the scenes. Businesses will face a lot of challenges because we've turned everybody into experts. Everybody can learn everything transparently. I don't think everyone likes that. (Interviewee E.)

Some suggested that to overcome resistance, government-led initiatives mandating the use of blockchain platforms could be one way of getting organisations aboard. Others saw compatibility with other IT systems and interoperability between different blockchains as a challenge:

> Putting blockchain in the country, not only for our company, but the whole supply chain, you can imagine that our WMS [warehouse management system] would be on board, SAP systems would be on board, Oracle would be on board, the banking system would be on blockchain as well, electronic payment will be active in real-time… I can guarantee that would be the most challenging part of blockchain. (Interviewee E.)

Interviewee C echoed this view:

> Same with EDI [electronic data interchange] transactions, we need to agree on how to use it. The industry has not succeeded. So, what we see are many different standards. And again, if there will be many different blockchains, how does this all connect the network together? Wouldn't this make the network even more complicated than what it was before?

The interviewees perceived the capacity of what blockchains can do at the moment to be another issue, especially regarding the latency problem:

> The speed of the technology in this moment is far too slow. So, if you put the entire supply chain [transactions] into a blockchain, this generates very low results and is not responding fast enough (to accommodate the fast-paced activities of supply chain), then I don't see how it will work. (Interviewee H.)

This is a valid point. Taking the example of Ethereum, one of the most popular blockchains used for smart contracts, it takes about 17 seconds for every transaction to be added to the ledger – a far cry from the milliseconds non-blockchain-based databases could achieve (Ream et al., 2016). As interviewee N put it, 'Ultimately, what we want is something that is quick, flexible and instantaneous, rather than waiting forever for your transactions to clear. That would not be an improvement'. But verification speed was not a universal concern; interviewee A, for example, did not consider this an issue, as their business transactions typically did not require that kind of speed.

The cost of implementing blockchain was perceived as another barrier. Interviewee L, for example, stated that 'the small companies would be weeded out due to lack of sufficient funds, while bigger companies may have ability [*sic*] to develop and maintain the technology, but gaining profits from it will be in the long-term, hence a low ROI'. Others disagreed, however, arguing that small companies are more agile and could be more adaptable to the technology; interviewee H said that 'the small ones, the start-up companies, they see it as an advantage and they could be the one to adopt quickly. We see newcomers such as XX and other [*sic*], they are the innovators… They could adopt a blockchain as a service model'.

Because distributed systems lack a central authority, some interviewees raised concerns about issues related to resolving disputes. They also identified security and privacy concerns, further compounded by cases such as the NiceHash case in 2017, in which hackers broke into a Slovenia-based Bitcoin-mining marketplace and stole nearly US$64 million in Bitcoin. Interviewee E commented:

> One of the first challenges is data security for sure…we have to deal with so many layers, including the owner of the product, the manufacturer, the buyer. So, we have to make sure that all of us have the same agreement in terms of what information should be added to the blockchain and who else are [*sic*] within the chain to access the information… We are also regulated by our government as to where we can store our data and by how much [*sic*].

Some IT experts (interviewees L and N) suggested that during initial implementation attempts, organisations should deploy permissioned, private versions of blockchains. Finally, they pointed out that the data-input problem must be solved, as the information contained within blockchains will only be as accurate as the incoming raw data. Interviewee I commented that even with automatic data capturing and the fact that data is directly input into blockchains, the sensors can still be tampered with.

Table 4: Perceived challenges of blockchain usage in supply chains

Perceived challenges of blockchain usage in supply chains	**Explanation**	**Number of entries by experts**
Confidence and related necessity issues	• Many organisations are still unsure of blockchain technicalities, functions or benefits • Technology is still in its infancy • The concept of the technology is complex and difficult to grasp • Many problems could be solved simply with traditional databases and information systems	A, B, G, H, I, L, M (7)
Cultural, procedural, governance and collaboration issues	• Changing people's mind-sets and operational protocols is a major hurdle • Numerous stakeholders would be involved or affected • Stakeholders may develop conflicting objectives • Cultural hurdles against new innovations could present a barrier to blockchain deployment • Data ownership and intellectual property are difficult to define	A, D, F, G, H, I, J, L, M, N (10)

Data input and information-sharing issues	• Ensuring the integrity of input data is very difficult • Convincing partners and customers to provide their data will be challenging • Large amounts of data will be collected, so sifting through it would also pose a challenge	A, E, F, I, J, L, M, N (8)
Technological and network interoperability issues	• The question of how one blockchain will be used alongside other blockchains or other available systems should be addressed • Introducing blockchains may overcomplicate the existing supply chain ecosystem • The lack of standards presents a problem	C, D, E, G, H, I, K, L, N (9)
Cost, privacy, legal and security issues	• Costly implementation • Resistance to high level of transparency among supply chain actors • Commercially sensitive information and privacy must be protected • Unethical behaviour (e.g. data manipulation) may still occur if data is entered manually • Regulatory uncertainties and illegal use of blockchains may occur, as with Silk Road • Supply chains could suffer damage if their systems are hacked	C, D, E, F, G, I, J, K, L, N (10)

5. Discussion

This research set out to explore how blockchain technology may transform supply chains. We did so by exploring the answers to our three RQs: What are blockchains' perceived benefits to supply chains (RQ1), where are disruptions mostly likely to occur (RQ2) and what are the challenges to blockchains' further diffusion in supply chains? (RQ3) Our literature review found that the perceived benefits, such as improved tracking and traceability, efficiency gains through automation, and the reduction of complexities, are the main reasons why blockchains matter to supply chains. Via a cognitive analysis of 14 experts' interviews, we further identified some of the expected gains from blockchain usage to include improvements to supply chain visibility and operational improvements, secure information sharing and the building of trust, thus answering RQ1.

Our empirical research allowed us to further extricate the areas where blockchains may penetrate and bring value to supply chains – disintermediation, smart contracts, the simplification and digitalisation of supply chain processes, and extended visibility and traceability – thus answering RQ2. Our participants also paid particular attention to crucial supply chains. We captured a number of challenges to blockchains' further diffusion, ranging from technological complexities and cultural and collaborative issues to cost, security and disintermediation concerns, which answered RQ3.

5.1. Theoretical contributions

Although sensemaking theory is well established in the discipline of organisation and management studies, it has yet to be used in the fields of operations management (OM) and supply chain management (SCM). Using a keyword search (sensemaking* or sense making*) in popular OM/SCM journals such as the *International Journal of Operations and Production Management*, the *International Journal of Production Economics*, *Supply Chain Management: An International Journal*, the *Journal of Operations Management* and the *Journal of Supply Chain Management*, among others, we found that no one has deliberately used this theoretical lens to investigate supply chain–related issues. In fact, Chicksand et al.'s (2012) literature review identified 17 dominant theories used in the field of purchasing and supply chain management, yet sensemaking was clearly absent.

Our analysis of sensemaking by supply chain experts provides unique insights because it (1) explicates pre-decisional activities and (2) describes how supply chain experts diagnose the symptoms evident from blockchains and then interpret and construct meaning to manage the ambiguity and uncertainty caused by the emergence of blockchains. Therefore we contribute to the supply chain literature by demonstrating the usefulness of sensemaking theory as an alternative lens in investigating contemporary supply chain phenomena such as blockchain technology. We add further insights to the stream of technology adoption studies by providing evidence of the importance of pre-adoption sensemaking. We assert that technological pre-adoption cannot be better understood without considering multiple interpretations of supply chain actors.

We further extend the theories of prospective sensemaking in this study. As exemplified by Sandberg and Tsoukas (2015) and Maitlis and Christianson (2014), the sensemaking literature is dominated by traditional retrospective research. Prospective sensemaking, although it underpins important organisational processes such as strategy making, entrepreneurship and innovation, is under-researched and under-theorised. Our research reveals the emerging cognitive structure of supply chain experts when they engage in future-oriented sensemaking, and it shows how they resolve technology equivocality and construct 'meaning' – i.e. individuals 'select' a contextually rational explanation from among those available that will best utilise their past wisdom and experience to develop a new frame of what blockchains mean for them. We provide empirical evidence on how the participants' combined frames on benefits, applications and challenges led to a salience of beliefs and expectations about blockchain technology usage in supply chains. The managerial foresights generated are not so much a matter of accuracy but of plausibility, acceptability and strategic possibilities that matter to individual accounts. As Kaplan and Orlikowski (2013) rightly argue, though the future will likely not turn out exactly as projected, this does not mean that our foresight practices are of no use. The articulation of projections shapes people's attention and deliberation, influences investment efforts and supports future decision-making about where to deploy blockchains.

We have also enriched the emerging field of behavioural operations research (BOR) by applying sensemaking theory to this technological-foresight exercise. Currently the majority of BOR studies investigate inventory and production decisions, supplier relations/contracting, and product development issues by utilising either experimentation, surveys, math modelling or simulation methods (Croson et al., 2013; Bendoly et al., 2010). Only a small proportion of studies use qualitative/conceptual approaches. Our study uses expert interviews and a soft OR technique of cognitive mapping to demonstrate how cognitive frameworks shape people's way of making sense of emerging blockchain technology. We thus add to the diversity of methodological approaches to BOR.

Finally, we have contributed to the supply chain literature by articulating the reasons why blockchain technology is important to supply chain management. We have done so by locating areas where blockchains may bring value to supply chains and by elucidating the current challenges for the technology's further diffusion. Our research is one of the very few to have explicitly explored how blockchains may transform supply chain practices. Our research thereby offers valuable insights to SCM and OM researchers, thus laying the foundation to aid their understanding and to motivate them to explore this emerging technology further.

5.2. Practical contributions

Our research offers several valuable insights to supply chain practitioners and will prepare them for the potential uptake and exploitation of this disruptive technology. Having an understanding of areas where blockchains may bring value to supply chains, or disrupt the status quo, will help organisations develop their strategies of adoption. Our findings will help senior executives decide in which areas to pilot blockchain initiatives if they wish to move to the next stage of piloting and implementation. They could opt either for the easier benefits of extended traceability or to pursue more transformative changes through smart contracts.

Without using the sensemaking process and the understanding it allows, supply chain organisations will likely be less proactive in reacting to the potential disruptions caused by blockchains, or in managing the implementation of blockchain initiatives and the strategic changes necessary within and between organisations. Our work highlights the cognitive importance of using mental models; we suggest that these models may be used as intervening devices or tools. Together with other material artefacts, organisations could 'scaffold' behaviours towards desirable strategic changes and innovations. Understanding the social construction of sensemaking should ultimately help IT service providers to design future blockchain systems more suitable for supply chains, if they take the issues we have identified into consideration.

6. Limitations and conclusion

The aim of our research was to explore how blockchains may transform supply chains in the future. Through an empirical study using 14 interviews with subject matter experts, we gained valuable insights into how supply chain actors make sense of this emerging technology, as well as the potential impact of blockchains on supply chains: the perceived benefits, areas of potential deployment and perceived challenges to the technology's further diffusion.

Although our research offers significant insights, the study was explorative in nature and did have a few limitations. Our expert interview format, though appropriate for an explorative study, could benefit from a more diverse range of participants, which could lead to more robust findings and a more in-depth understanding of the subject. Alternative methods such as the Delphi technique could be deployed for a more structured way of assessing and combining experts' judgements. We have focussed on individual sensemaking in our research, but future studies could investigate group/collective sensemaking and examine the interactions between experts on technological innovations.

Given the infancy of this technology, researchers have numerous opportunities for future blockchain-related studies. For example, one interesting avenue of research would be to examine whether blockchains will revolutionise the concept of trust in supply chains. Traditionally, to build trust, companies needed to establish long-term relationships with their supply chain partners or through mutual investments in the supply chain. With blockchains, companies need not 'trust' their partners to the same degree, since trust is pre-built into blockchain systems.

Researchers could also explore how digital currency or cryptocurrency could affect cash flow and supply chain structures. Supply chain partners could potentially start to trade and settle their payments using cryptocurrency. For instance, one company may wish to pay another to access the massive amounts of data generated by IoT devices. Research into how blockchains may disintegrate or reintegrate supply chains (i.e. by removing intermediaries) would also be worthwhile.

Different theoretical lenses and multi-methodological approaches should be deployed to understand the blockchain phenomenon, and disruptions may further contribute to our understanding of blockchains and the technology's diffusion within supply chains. Because the current acclaimed benefits of blockchains are mostly speculative and lacking in empirical evidence, a longitudinal case study that would follow the technology's pre-adoption, implementation and routinisation in supply chains would help to demystify and justify the value of blockchains in real practice. Finally, the dark side of blockchains (e.g. legal, ethical and security issues) should be explored, particularly regarding supply chain governance.

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Appendix 1: Expert interview protocol

I. Introduction
    a. Research motivation and objectives
    b. Confidentiality, research consent and permission for recording
II. General background information
    a. Interviewee's role and responsibility within the organisation, years of experience and areas of expertise
    b. How the interviewees have noted the rise of blockchain technology, and how they have scanned, interpreted and responded to this emerging technology
III. Detailed interview questions

The following interview questions will act as the principal topics of discussion, although we will use follow-up questions if necessary, depending on the direction of the interview.

<u>Technical</u>

1. What is your opinion about the current research and developments on the utilisation of blockchains beyond Bitcoin?
2. Are there any current or potential applications of blockchains into an industry that you find most interesting?
3. Do you think that the benefits of blockchains, as the technology behind Bitcoin, are transferrable to other industries?
4. What are your main concerns about the adaptation of blockchains at a wider scale or in other industries?
5. In your opinion, how great are the security risks (e.g. miner collision, double spending, blockchain forks) that stem from dishonest blockchain miners? Could privatising whole or part of the network in a supply chain be a solution?
6. One of the journal articles we reviewed stated that if all nodes participating within a blockchain have the same interests to act honestly (e.g. in maintaining business professionalism), there will be no more need for transaction verification or for mining. What is your opinion on this?

<u>Supply chains</u>

7. From your understanding of the technology, do you see a potential utilisation of blockchains in supply chains?
8. We found three general themes regarding blockchains' application to non-Bitcoin sectors: to eliminate intermediaries, improve visibility and optimise processes. In your opinion, which one might be the most important to supply chains?
9. Which benefits of the technology's implementation do you think would be most attractive to supply chain businesses?
10. What do you think are the main hurdles in implementing blockchain-based solutions (e.g. ledger systems, provenance checking and smart contracts) in supply chains?

11. Which criticisms or drawbacks do you think might drive supply chain practitioners away from the technology?
12. Do you believe that this technology will eventually remove all supply chain intermediaries?
13. Who do you think will likely be the first to adopt this technology, and who will be affected?

General

14. We found three general themes regarding blockchains' application to non-Bitcoin sectors: to eliminate intermediaries, improve visibility and optimise processes. In your opinion, how justifiable are these purposes to blockchains' current level of development?
15. In terms of timelines, how close or far away do you think major industries are from achieving blockchain utilisation for these purposes?

Figures

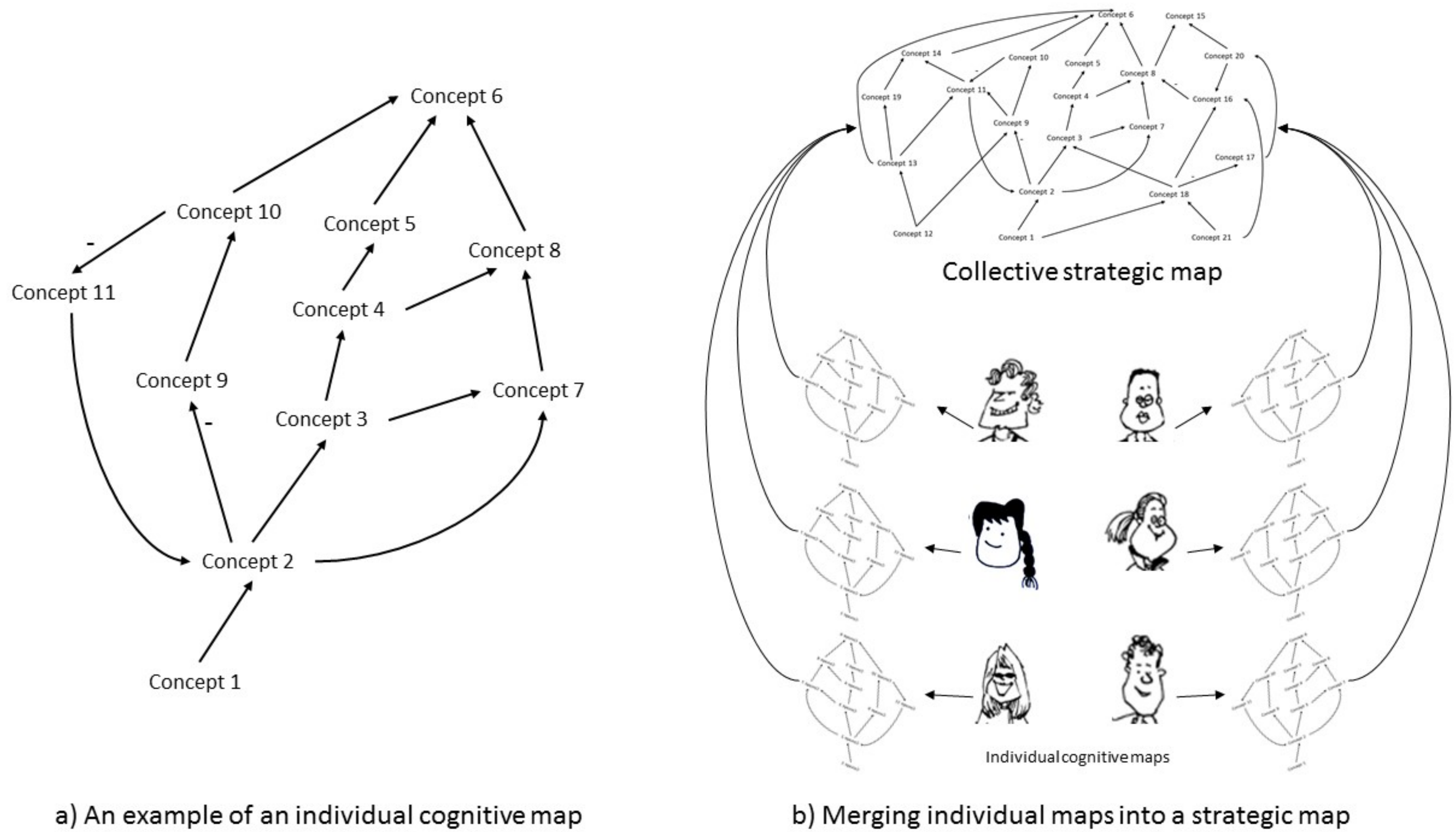

Figure 1: The development of individual and collective cognitive maps (adapted from Pidd, 2011)

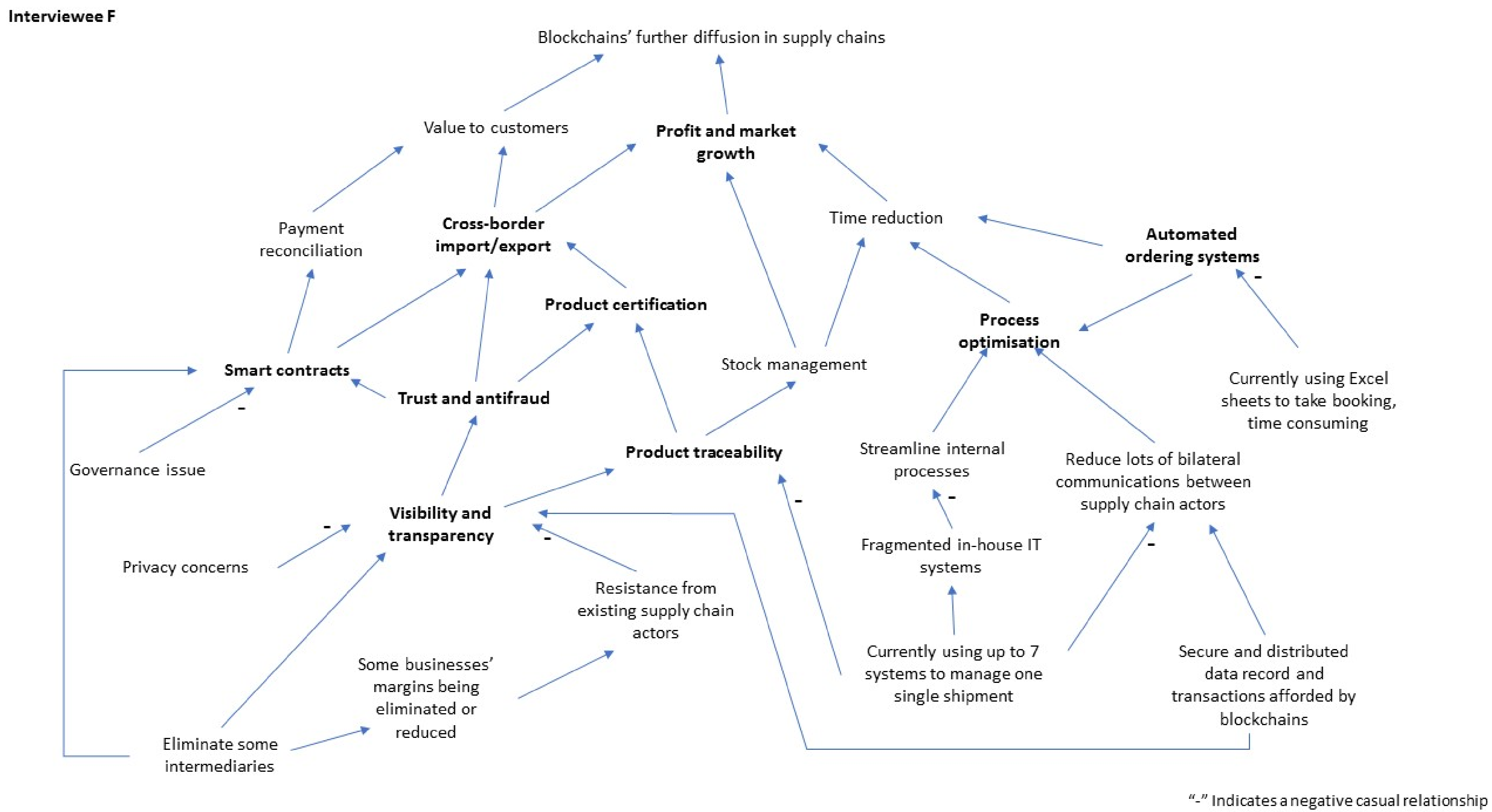

Figure 2a: Cognitive map of expert F

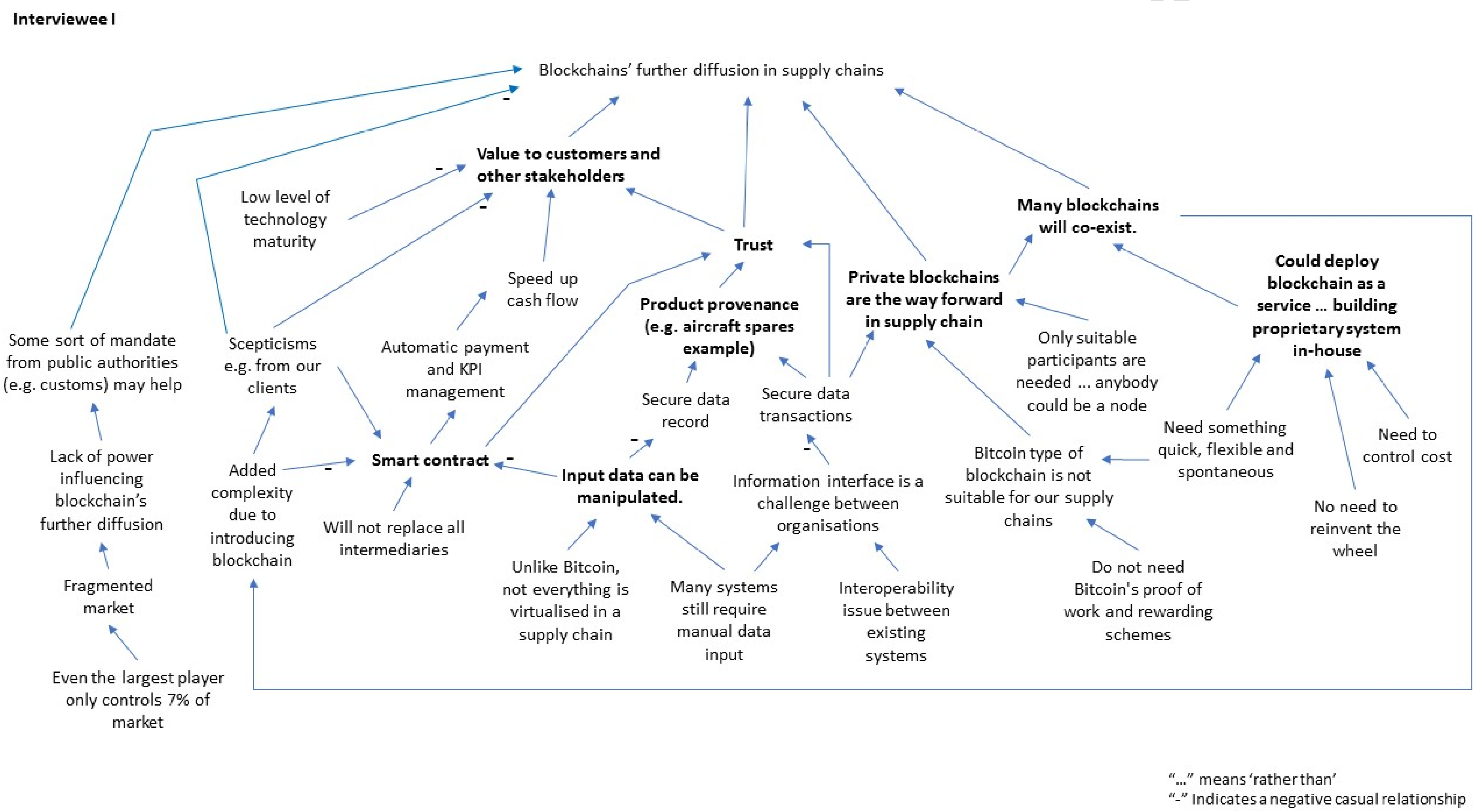

Figure 2b: Cognitive map of expert I

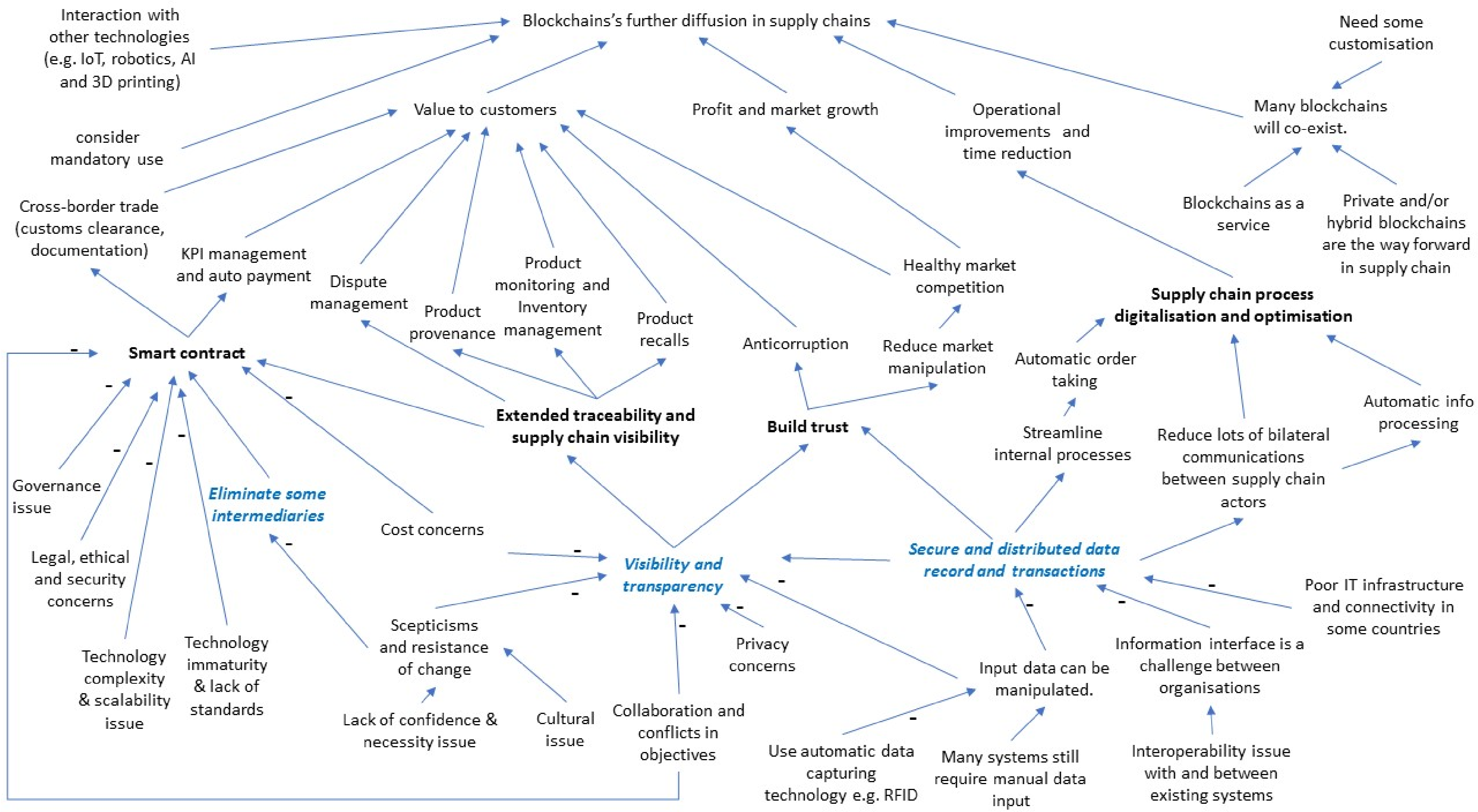

Figure 3: Strategic cognitive map